MR No. L5C12b

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

.ORIGINALLY ISSUED
March 1945 as
Memorandum Report L5C12b

AN ESTIMATE OF THE EFFECT OF ENGINE SUPERCHARGING ON THE

TAKE-OFF THRUST OF A TYPICAL HELICOPTER AT

DIFFERENT ALTITUDES AND TEMPERATURES

TED No. NACA 1301

By F. J. Bailey, Jr.,and T. J. Voglewede

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NACA

WASHINGTON

L-592

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

and the

Bureau of Aeronautics, Navy Department

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SUMMARY

Calculations for a typical helicopter indicate that incorporation of a small amount of supercharging should substantially increase its take-off thrust and useful load for a wide range of airport altitudes and air temperatures.

INTRODUCTION

As in the case of the airplane, the helicopter can cruise at powers well below those required for safe take-off in moderate or low-wind conditions. It has been suggested, therefore, that the failure of helicopter and helicopter engine designers to take advantage of the temporary increases in power made possible by modern engine developments in superchargers and high-octane fuels may be limiting the usefulness of the helicopter. As a first step in examining the correctness of this suggestion a brief theoretical study was made of the increases in take-off thrust that would be made possible at different times of the year in various parts of the country by incorporation of a small amount of supercharging in a typical helicopter. The results of this study are given in the present paper.

SYMBOLS

For convenience the symbols used in the analysis are defined in the following list:

bhp   brake horsepower

ihp   indicated horsepower

shp   supercharger horsepower

fhp   friction horsepower

p_m manifold pressure, inches of mercury

p_o atmospheric pressure, inches of mercury

Δp pressure drop from inlet to manifold (or to supercharger entrance for supercharged engine), inches of mercury

r_s pressure ratio across supercharger

r cylinder compression ratio

σ free-air density ratio

W_a charge air flow, pounds per second

T_m dry manifold temperature, °F absolute

T_o free-air temperature, °F absolute

ΔT temperature rise across supercharger, °F

η supercharger adiabatic efficiency

J 778 foot-pounds per Btu

c_p specific heat of air at constant pressure (=0.24)

γ specific heat ratio for air (=1.40)

N_c number of cylinders

D_c cylinder diameter, inches

S   piston stroke, inches

N   engine speed, rpm

C_T rotor thrust coefficient = $\dfrac{T}{\pi R^2 \rho (\Omega R)^2}$

C_Q rotor torque coefficient = $\dfrac{Q}{\pi R^3 \rho (\Omega R)^2}$

T   rotor thrust, pounds

Q   rotor torque, pound-feet

Ω rotor speed, radians per second

R   rotor radius, feet

ρ free-air density, slugs per foot^3

δ blade element profile-drag coefficient

α blade element angle of attack, radians

METHOD OF ANALYSIS

Performance of unsupercharged engine.- A typical unsupercharged helicopter engine was selected. This engine was assumed to have the following characteristics at its rated power for continuous full-throttle operation under standard sea-level conditions.

N_c 7

D_c 4.875 inches

S   4.25 inches

r   6.4

N   2100 rpm

p_m 28.7 inches of mercury ($\Delta p = (29.92 - 28.7)$
                                           $= 1.22$ inches of mercury)

ihp   200

$$fhp = 15 \times 10^{-10} \, N_c \, (D_c SN)^2 = 20 \quad \text{(reference 1)}$$

$$bhp = ihp - fhp = 180$$

The brake horsepower delivered by this engine at full throttle at 2100 rpm over a range of temperatures from -40° to 120° F and a range of pressure altitudes from 0 to 6000 feet was calculated on the assumption that

$$ihp \, \propto \left(p_m - \frac{p_o}{r} \right) T_m^{-0.58} \qquad \text{(references 1 and 2)}$$

$$p_m = p_o - \Delta p$$

$$\Delta p \propto \frac{W_a^2}{\sigma} \propto \frac{(ihp)^2}{\sigma}$$

Performance of supercharged engine.- The engine was then assumed to be fitted with a single-stage single-speed gear-driven supercharger designed for a pressure ratio sufficient to give 230 indicated horsepower at 2100 rpm at 2600 feet altitude at full throttle on a standard day. The value of 230 for the maximum permissible indicated horsepower represents an increase of 15 percent over that for continuous operation at standard sea-level conditions. This value was selected after study of a number of super-charged engines indicated that temporary increases in indicated mean effective pressure permitted for military or take-off operation ranged from 10 to 20 percent. It also corresponds to the indicated horsepower of the unsupercharged engine in full-throttle operation at sea level at a temperature of -55° F.

Under the design conditions the pressure ratio required was 1.3 which, with an assumed adiabatic efficiency of 75 percent, corresponds to a temperature rise across the supercharger of 53° F and a manifold pressure of 33.2 inches of mercury.

The power delivered by the supercharged engine at full throttle over the range of altitudes and temperatures was then calculated on the assumptions that

$$bhp = ihp - fhp - shp$$

$$ihp \, \propto \left(p_m - \frac{p_o}{r} \right) T_m^{-0.58}$$

$$T_m = T_o + \Delta T = T_o + 53^\circ$$

$$p_m = r_s (p_o - \Delta p)$$

$$r_s = \left(1 + \eta \frac{\Delta T}{T_o}\right)^{\frac{\gamma}{\gamma-1}} = \left(1 + 0.75 \frac{53}{T_o}\right)^{3.5}$$

$$\Delta p \propto \frac{(ihp)^2}{\sigma}$$

$$fhp = 20$$

$$shp = \frac{W_a J c_p \Delta T}{550}$$

$$= 0.030 \; ihp \quad when \quad W_a = \frac{6.0 \times ihp}{3600}$$

It was assumed that the throttle would be used to prevent the indicated horsepower from exceeding the selected maximum permissible value of 230.

Performance of rotor.- The helicopter rotor was assumed to have the following characteristics, which are appropriate for a machine having a gross weight of approximately 2500 pounds:

R, feet 19
Ω, radius per second 23.58
Solidity 0.06
Blade plan form . . . . Constant chord and incidence
c_{d_o} . . . . 0.01 + 0.3a^2

The relation between rotor static thrust and torque coefficients was derived from figure 15 of reference 3 and is plotted in figure 1. For convenience in the computations the expression

$$C_T = 0.00235 \left(10^4 C_Q - 0.75\right)^{0.708}$$

was substituted for the curve. The curve may be considered to represent the hovering performance of current rotors with fabric-covered blades.

The rotor thrust was calculated for both the super-
charged and unsupercharged conditions over the range of
altitudes and temperatures, on the assumption that 80 per-
cent of the engine brake horsepower was delivered to the
rotor.

RESULTS AND DISCUSSION

The calculated values of engine brake horsepower for
the two conditions are presented in figure 2. The increase
in static thrust resulting from the increased brake horse-
power of the supercharged engine is shown in figure 3.
It is evident that the take-off thrust increases made
possible by supercharging are large in relation to the
probable weight of the supercharger, particularly when
operation is to be from airports above sea level at
moderate or summer temperatures. For example, installation
of the supercharger would increase the useful load at
take-off from a 1000-foot-high airport at 75° F by 350 pounds,
or about 70 percent, even when a rather generous allowance
of 50 pounds is made for the weight of the supercharger.

CONCLUDING REMARKS

The foregoing calculations indicate that incorporation
of supercharged engines in current helicopters may be
expected to increase substantially the useful load at take-
off from most airports in any but extremely cold weather.
The problem of developing suitable supercharged engines
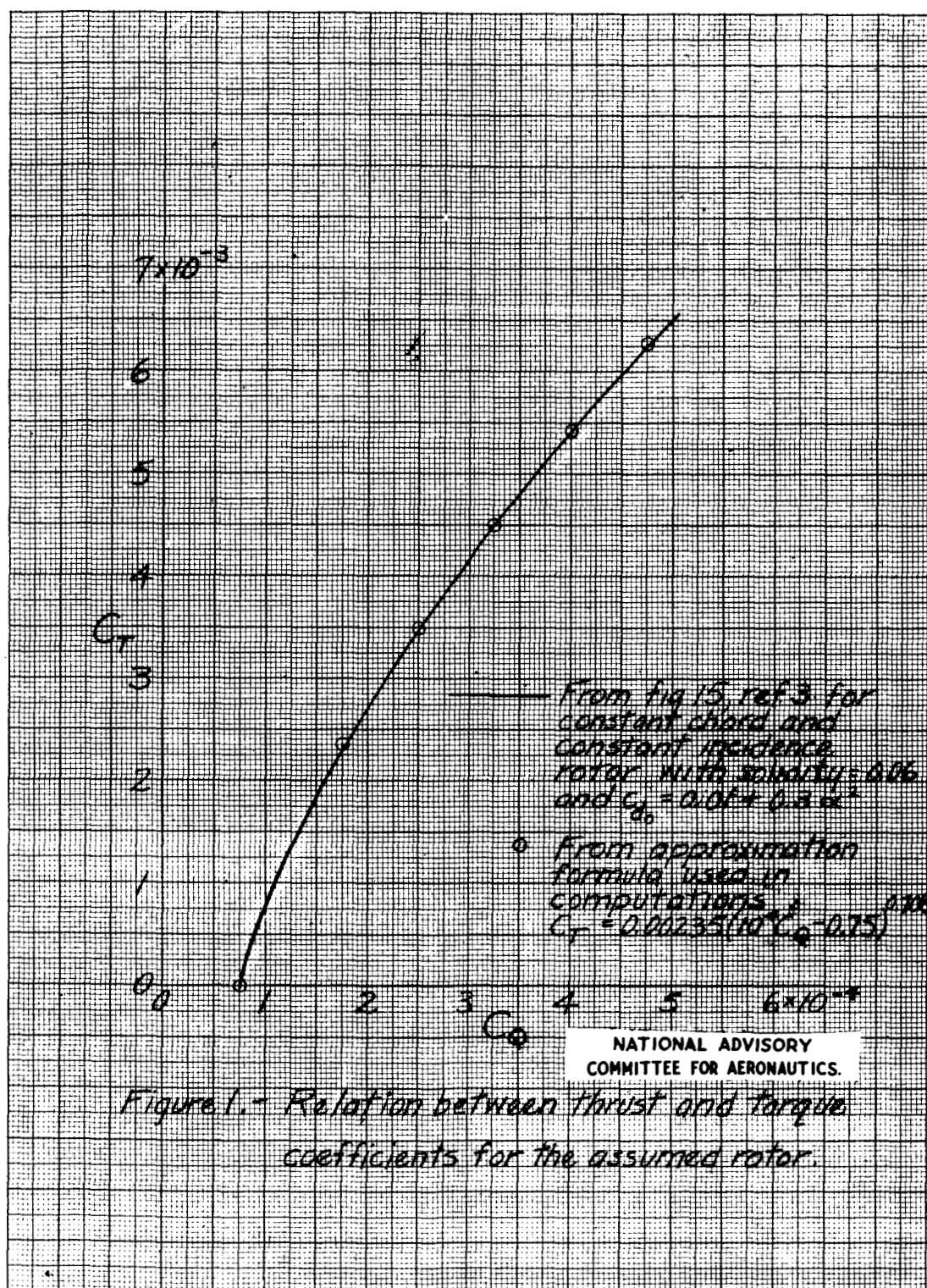for helicopters appears to warrant further consideration.

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    National Advisory Committee for Aeronautics
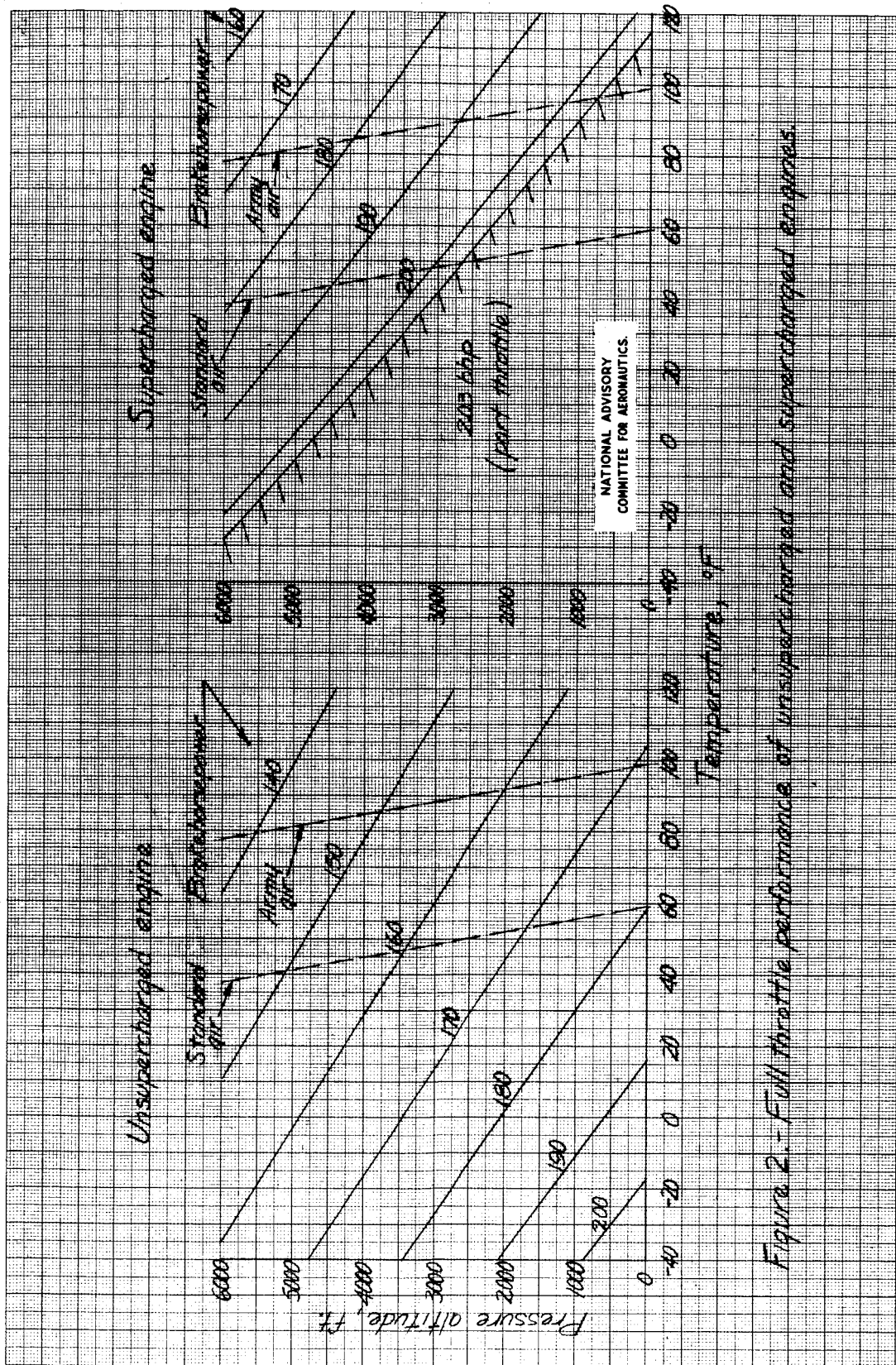   Langley Field, Va.

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L-592

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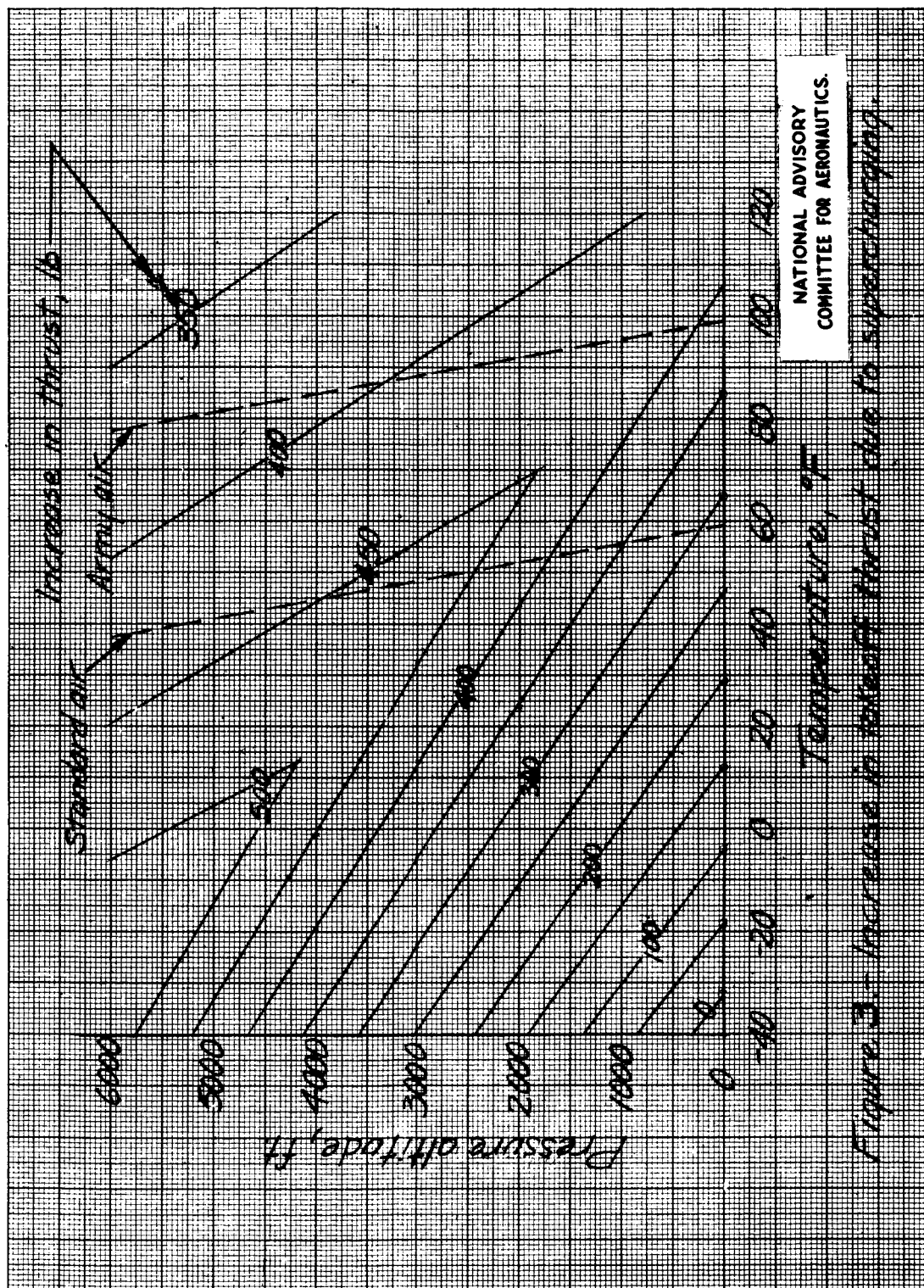
Figure 1.- Relation between thrust and torque coefficients for the assumed rotor

L-592

Figure 2.- Full throttle performance of unsupercharged and supercharged engines.

L-592

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Figure 3.- Increase in total thrust due to supercharging.